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Combining spatial analysis with MCDA for the siting of healthcare facilities

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ABSTRACT

Site selection of healthcare facilities is a typical ill-structured decision problem since it involves multiple criteria and sometimes conflicting stakeholders. Nowadays the site selection problem is ignored by most of the existing evaluation tools. Through a deep literature review the research proposes an evaluation system divided into four criteria (Functional quality, Location quality, Environmental quality, Economical aspects), each in turn composed by sub-criteria supported by the methodology of Multi-Criteria Decision Analysis (MCDA), with the aim of assessing the land suitability for new healthcare structures, in order to improve the transparency and robustness of the decision-making process. After that, spatial component has been added to MCDA using Geographic Information System (GIS). The Multi-Criteria-Spatial Decision Support Systems (MC-SDSS) allow to address choices by an integrated knowledge about territory and by the explicit consideration of the spatial dimension of decision problems. The case study selected to test this method is "La Città della Salute", in the city of Milan, Italy, a project aimed to answer to scientific and cultural changes of contemporary medicine. The focus of the research is to identify suitability maps able to verify the adequacy of the territory in an adaptive perspective, expanding the alternatives' domain.

1. Introduction

The location of healthcare facilities can be considered a typical ill-structured decision problem since it involves issues belonging to different fields of research and there are several and sometimes conflicting stakeholders to take into consideration. It means that, in order to solve it, it is necessary a multidisciplinary approach able to consider all these aspects and to satisfy actors affected by the hospitals' location.

According to the literature analysed on this topic, it is possible to recognize two main problems capable to influence the decision problem. The first involves the set of criteria considered that should be able to describe the complexity inherent in the problem and the second one concerns the variety of stakeholders with their own interests to fulfil and power to prioritize. In fact, first of all it is mandatory to contextualize the hospital location problem as a planning problem (Doerner et al., 2007) able to influence the access to healthcare services by all citizens (Murad, 2007).

According to the first issue, it is possible to underline how the site selection is a typical multicriteria decision making problem including both quantitative and qualitative criteria (Kahraman et al., 2003) belonging to different fields and able to move and to consider multiple resources (Murad, 2007).

Considering the second point, Burkey et al. (2012) argue how the location of healthcare facilities is also effected by many different stakeholders as patients, doctors, politicians and people that daily or rarely visit the hospital. Nowadays in particular, the population growth and the migration to urban areas (Abdullahi et al., 2014) are forcing cities to answer to primary needs such as the hospital location and choosing the right site could have significant effects on accessibility to health services (Beheshtifar and Alimoahmmadi, 2015) and to the satisfaction of stakeholders' expectation.

From this introduction it is clear the complexity of the decision problem investigated and the necessity to manage it with a decision support system based on multidimensional criteria and able to consider as much as possible the different categories of the stakeholders involved, since at the moment it is solved by a case by case process (Soltani and Marandi, 2011) and an objective methodology is still missing.

Given the above emerging research issues, the aim of the current work is to define a Decision Support System able to support the Decision-Maker (DM) and to provide information regarding all the aspects inherent to the problem and in detail, considering simultaneously functional, locational, environmental and economic issues. From the proposed evaluation framework, it is possible moreover to obtain a comprehensive overview about weaknesses and threats of the areas under investigation and, since the decision problem is characterized by

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spatial variables (Oppio et al., 2016) the combination of the Multi-Criteria Decision Analysis (MCDA) with the Geographic Information System (GIS) is suggested. In fact, the Multicriteria-Spatial Decision Support System (MC-SDSS) can provide an integrated knowledge about territory and to explicitly consider the spatial dimension of the decision problems.

The paper is divided into 4 parts. The Literature review section contextualizes the research within the existing literature about the combination of MCDA and GIS with a focus on the location of healthcare facilities. The Materials and Methods describes the case study and the evaluation framework defined to solve the decision problem under investigation, presenting the multi-methodological approach and the development of the model. The Results and Discussion section points out the main findings from its application, summarising the conclusions emerging from the analysis and highlighting strengths and weaknesses. The last section underlines future research lines and how the evaluation framework could provide an effective support to DM with respect to policy implications.

2. Literature review

MCDA and GIS are two different research fields, the first one has been defined by Roy (1985) as a revolution in the field of the operational research while the second is a set of tools able to collect, store, retrieve at will, transform and display spatial data according to a specific purpose (Borrough and McDonnell, 1998). MCDA and GIS can both benefit one of the other in order to manage and analyse spatial problem and evaluate and rank different alternatives (Densham and Goodchild, 1989; Li et al., 2004; Ferretti, 2012). In fact, the Multicriteria-Spatial Decision Support Systems (MC-SDSS) are able to support the DM in processes in the field of land management, land use planning and more in general spatial planning (Torrieri and Batà, 2017).

With the aim of investigating which fields have been explored by the combined use of MCDA and GIS and for which location problem, a literature review has been carried out with the support of the Scopus database by using the following set of keyword: "MCDA" or "Multi-Criteria Decision Analysis" and "GIS" or "Geographic Information System" and "Location". 100 documents resulted from the research. The analysis (Fig. 1) shows how the interest in combining MCDA and GIS to solve location problems is quite recent and is increased in the last years.

In particular the peak is recorded in 2016 and different research fields are investigating the topic, from the Environmental Science to the Economics, Econometrics and Finance. The investigation has been focused on the year, research areas, contexts, countries where the decision problem has been solved and whether it has been applied on real case studies. From the analysis it is clear how the research areas that mostly investigate the location problem are focused on the Energy demand, Risk assessment, Waste management, Geology and Urban planning. In fact, the decision problems solved concerns, for example, the identification of locations for the installation of wind farm (Gigović et al., 2017) or to prevent natural hazard (Tufekci et al., 2018), the landfill site selection (Mat et al., 2016), the evaluation and characterization of groundwater quality (Jhariya et al., 2017) or the rural highway route location (Abdul-Mawjoud and Jamel, 2016). It proves the important support of MC-SDSS to solve different location problems. Another important point highlighted by the research, shows how only one document analysed a case study set in Italy (Borgogno-Mondino et al., 2015) concerning the generation of maps useful for urban planners, and then, even more important is the low percentage of papers that deals with healthcare facilities. More in detail, there are two papers focused on health problems and other two concerning the location problem. Varatharajan et al. (2017) investigated this issue under an epidemiological point of view and Ho et al. (2015) aimed to reduce the mortality due to heat events. For what concern the location, the research of Hariz et al. (2017) aimed to identify the most suitable area to site an incinerator to serve healthcare facilities while in 2009, Vahidnia et al., combined the use of MCDA and in particular of the Fuzzy Analytic Hierarchy Method (FAHM) and the GIS for the hospital site selection.

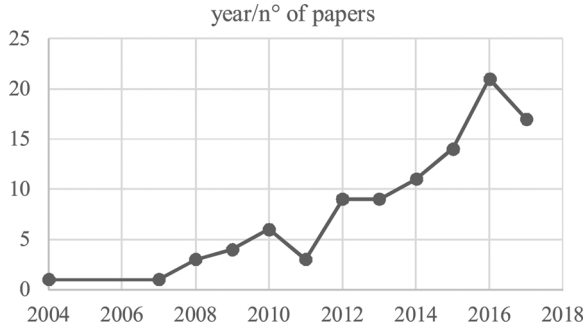


Fig. 1. Literature review: year/n° of papers.

Since only one paper was focused on the location of healthcare facilities, a further investigation has been performed stressing the decision problem with the aim to analyse how other scholars faced this challenge. In order to broaden the research but keeping the focus on the same topics, the literature review has been carried out specifying as keywords "hospital" or "healthcare facility"; maintaining "GIS" or "Geographic Information System" and "Location"; but removing "MCDA" or "Multi-Criteria Decision Analysis" since considered too narrow. 425 documents resulted from the research; a first sort has been carried out starting from the title and 23 documents resulted from the first selection. Then a second sort has been performed through the abstracts and 14 documents have been picked. Table 1 shows the results of the literature review. Even if the context of investigation and the aim of the papers are the same; what is different is the type of building/facilities to locate. In some articles it is a general hospital while in some others it is a specialized hospital for aging people (Kim et al., 2015) or a Neonatal Intensive Care Unit (Noon and Hankins, 2001).

Despite it emerges a case by case approach rather than a common methodology, the combination of georeferenced visual systems with the multicriteria analysis, able to decompose a complex problem in its elementary parts, easier to understand and to solve as the Analytic Hierarchy Method (AHP) or the Analytic network process (ANP), resulted as the favourite evaluation technique. Moreover, this further analysis confirms the previous assumptions, namely the lack of Italian case studies aimed to face this kind of decision problem and the increasing interest in the last years.

3. Material and methods

This section is divided in two paragraphs, the first one will present the Case study under investigation to test the methodology while the second one will describe the Multi-methodological framework defined to solve the decision problem and in particular its stages, namely the definition of set of criteria, the criteria weight elicitation, the standardization functions and the aggregation of the results.

3.1. Case study

In Italy, health policies and planning decisions are taken by regional bodies that have too often conflicting interests with local authorities. Considering the city of Milan, Lombardy region, where is located the pilot case study analysed by this paper, according to a morphological and spatial analysis conducted by Dell'Ovo and Capolongo (2016) on the location of existing healthcare facilities in European capitals and major Italian cities, it is possible to draw some consideration on Milanese hospitals. In detail, it is possible to count around thirty hospitals of different size, according to the number of beds available, and with different specializations. Most of them have been realized between the

Table 1
Literature Review focused on the Location of healthcare facilities.

Authors	Country	Context	Method
Rahimi et al. (2017)	Iran	Select optimal locations for establishing new hospitals in Shiraz and assess the location of the existing hospitals in Shiraz	GIS + AHP
Ye and Kim (2016)	USA	Locating healthcare facilities	Net-MCLP + Net-LSCP + GIS
Eldemir and Onden (2016)	Turkey	Selecting construction sites for the new hospitals	AHP-GIS
Kim et al. (2015)	USA	Hospital site selection for an aging population	web-based GIS tools
Lee and Moon (2014)	South Korea	Info regarding hospital distribution	Statistical Geographical Information System
Abdullahi et al. (2014)	Iran	Site suitability assessment for hospitals	AHP and OLS
Faruque et al. (2012)	Canada	Selecting optimal locations for new healthcare facilities in remote region	SatScan + GIS
Burkey et al. (2012)	USA	Investigating the effects of hospitals' location on the geographic accessibility of health care	Microsoft MapPoint 2004
Gu et al. (2011)	Canada	Health care facility planning	multi-criteria + GIS
Soltani and Marandi (2011)	Iran	Hospital site selection	FANP + GIS
Vahidnia et al. (2009)	Iran	Creating a well-distributed network of hospitals	FAHP + GIS
Schuurman et al. (2008)	Canada	Creating successful health policy and location of resources	GIS
Ramani et al. (2007)	India	Provide a public private partnership (PPP) model for urban health centres (UHC) in developing countries	GIS
Noon and Hankins (2001)	USA	Supporting the decisions of locating and sizing a proposed Neonatal Intensive Care Unit	GIS-based Market Analysis

50 s and the 90s, it means that possibly the buildings are not anymore adequate to host the current function and to answer to contemporaneous needs of the population. Considering their location in the whole city it is clear how they are almost equally distributed in the consolidated city and in suburban areas (54% VS 46%).

The decision about the site for the pilot case study – the location of "La Città della Salute" – has been taken after a long time and with no transparency at all about the reasons of selecting one area instead of another among the potential candidate sites. The project was born with the purpose to relocate two existing specialized hospitals in one unique structure in order to answer to the scientific and cultural changes of contemporary medicine and population medical needs. The project has been defined in the early 2000 s and different locations have been proposed during these years. In 2008 (Fig. 2) it was proposed an area close to the existing Hospital Luigi Sacco in the North-West part of the city of Milan and after 4 years it has been changed and moved to another one, where at the moment is located an abandoned industry. According to new agreements the two existing hospitals are going to be relocated around the 2021. The process of area selection has not been supported by any specific Decision Support System able to evaluate the suitability of the site, but it has been guided only by economic interests.

The multi-methodological evaluation framework defined in this paper aims to address the DM in the process of hospitals new site selection. It also suggests to critically review the decision process as it has been developed across the last 17 years.

3.2. Multi-methodological framework

Starting from the analysis of the State of the Art, a multi-methodological spatial decision support system has been defined and then applied to the case study above described.

3.2.1. Methodology

Fig. 3 shows the methodology of this study which consists of different stages that can be gathered together in four main phases. The first one consists of the definition of a suitable set of criteria. The second one is the collection of spatial information regarding the criteria identified in order to create Source Maps, Criterion Maps and, after standardization, Suitability Maps. The third step includes the Criteria weight elicitation aimed to assign a different influence to the evaluation framework and the last phase contains the Aggregation of the Suitability Maps created for each criterion.

3.2.1.1. Modelling the spatial decision problem. The definition of a suitable set of criteria to solve the problem of the location of healthcare facilities started from the analysis of the State of the Art, and in particular it has involved the investigation of existing performance evaluation tools as the LEED Healthcare and the BREEAM Healthcare. These two rating systems are aimed to assess the building energy efficiency and environmental quality of hospitals and the contexts during the entire process, from the early construction stages to the operative ones. Moreover they are divided into main areas and the level of certification achieved by the building is calculated summing up credits of each section. Despite the selection of the site is

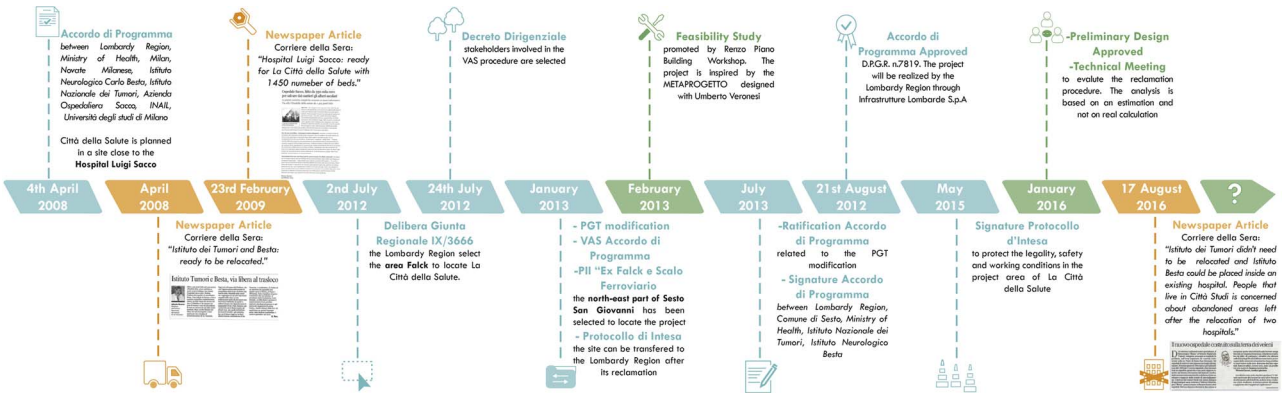


Fig. 2. Timeline: "Città della Salute" key phases (N.B. colour should be used).

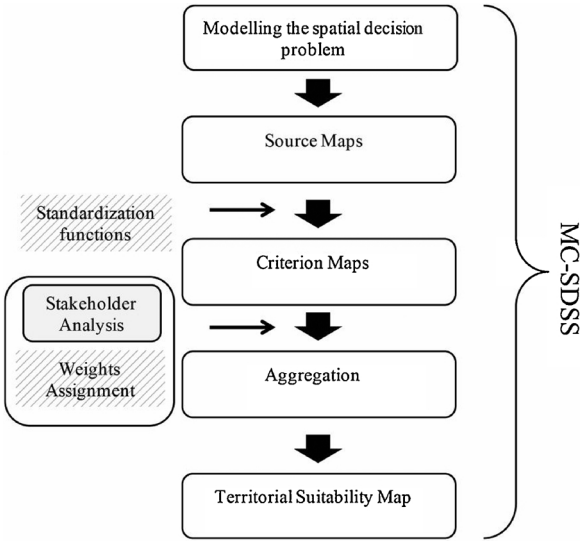


Fig. 3. Methodology flowchart.

included among the set of criteria of both the evaluation tools, they are focused on the evaluation of intrinsic features, namely energy and environmental performances, but there are some features useful to compose the evaluation framework defined by this work, such as to avoid the development of inappropriate sites, to reduce the environmental impact from new constructions and the promotion of sustainable transport systems. On the side of the literature review, the papers previously selected in the context of the location of healthcare facilities, have been further investigated putting in evidence not only the principal methodologies that have been used by scholars for facing the problem, but also pointing out the families of criteria generally used for modelling the decision problem (Dell'Ovo et al., 2017).

From the analysis the State of the Art a set of criteria has been defined and structured in a decision tree according to the objective to be achieved (Keeney, 1992; Ferretti and Pomarico, 2013). In particular, according to the purpose of finding the most suitable site to locate healthcare facilities, four main criteria have been defined, then specified by sub-criteria (Oppio et al., 2016). Table 2 presents the multi-methodological evaluation framework identified for the analysis that describes how different sub-criteria have been evaluated and considered to model the spatial decision problem. It is important to underline how the spatial nature of most of the criteria emerge, since GIS represents the common basis of the analysis and evaluation. There are some sub-criteria that will not be taken into account in this phase. In fact, in order to solve the decision problem, the Economic Aspects are going to be considered in a second phase, after the evaluation of the other three macro-areas. Once obtained the overall suitability map and identified a limited number of optimal sites (alternatives with the highest level of suitability in relation to the sub-criteria described and the related ranges defined) to locate healthcare facilities, it is possible to get information about the land cost, its current situation and the property. This kind of information is confidential and not in the public domain and need a more detailed evaluation. In detail, these business deals, in particular when concerns the location of public facilities, do not follow a regular process but negotiation processes and agreement, this is why the value cannot be decided on the screen but need a further step. Even information about the land ownership are not readily available. The framework defined aims to show a methodology based on information that can be easily found, but of course the collection of data and the study can be refined according to the context and materials available.

Since the purpose is to locate an hospital in the Municipality of Milan, existing hospitals and areas of hydrological and hydraulic instability (Mattia et al., 2016; Oppio et al., 2017) have been classified as prerequisites and constraints, and then sites affected by these two layer are not going to be considered in the analysis and evaluated as not suitable.

3.2.1.2. Model development. The spatial problem has been solved with the support of ArchGIS and in particular by using the extension Spatial Analyst that allows to aggregate different layers and create suitability maps. Initially a specific vector map (Source Map) – according to the description previously provided – has been linked to each sub-criterion. The design phase then consists of GIS operations, according to the type of information required (Euclidean Distance; Slope; Density; etc.), that result in raster maps in which it is possible already to define ranges (Criterion Map). Ranges have been evaluated case by case according to the sub-criterion under investigation, how it is possible to appreciate in Table 3.

After that, the first important step to build a suitability map, is the standardization by which different data need to be set with respect to a common measurement scale. In this phase, ranges previously defined are going to be reclassified in order to assign a value between 1 and 10. Higher values will be given to attributes within each dataset that are more suitable for locating the hospital (Table 3). The standardization allows to assign a dimensionless score (0–10) to different unit of measurement in order to be easily compared and aggregated (Fig. 4). The definition of specific ranges for each sub-criterion and the allocation of values have been addressed by comparing experts' opinions, analysing the Italian regulations and laws as well as the literature.

3.2.1.3. Criteria weight elicitation. Once the sub-criteria have been standardized, the second step concerns their aggregation to provide partial suitability maps for each criterion and then the final one.

In order to take into account the different importance of the criteria involved in the decision problem, a group of eight experts – namely architects and engineers skilled in hospital design and urban planning, in addition to doctors specialised in the field of public health – have been asked to assign a weight to the four criteria (Functional Quality; Location Quality; Environmental Quality; Economic Aspects). The pairwise comparison (Saaty, 1980) has been chosen as method for the criteria weight elicitation. Thus, the experts have been asked to express their judgement in form of paired comparison by using a ratio scale from 1 to 9 – the Saaty's fundamental scale – in order to find out the eigenvector for all the levels of the hierarchical evaluation framework. The final outcome, based on the aggregation of the experts' answers, highlights that the most important factors in determining the suitability of the site to locate hospitals are the Location Quality (34%) followed by Environmental Quality (25%). Then sub-criteria have been judged by one expert selected for each criterion. Table 4 shows the weights resulted from the interaction with the experts.

3.2.1.4. Aggregation of the suitability maps. The aggregation of the partial Suitability maps and the Overall Suitability map is given by the Weighted Linear Combination, WLC. Since each sub-criterion and criterion is defined by pixels, the following formula evaluates for each pixel its suitability according to the standardized score and the normalised weight:

$$Aj = \Sigma\ W_i X_i$$

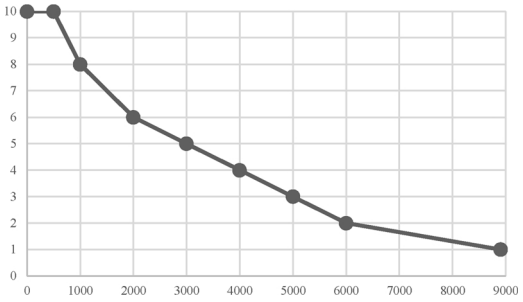
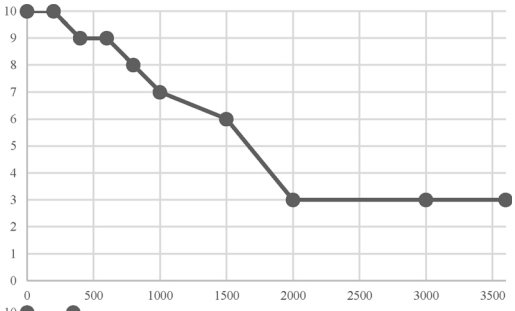
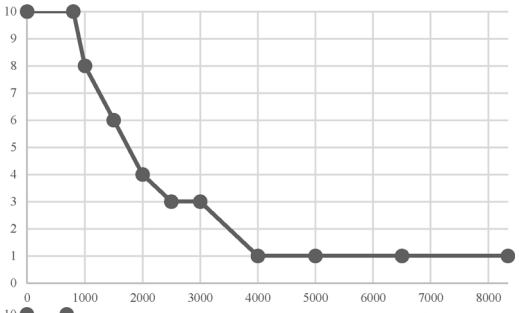
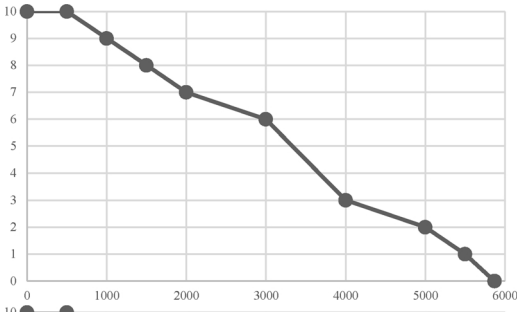
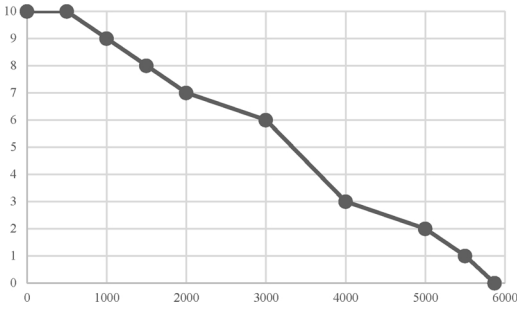
where:A_j alternatives represents the suitability of the *j*-th pixel in the final map; where:W_i is the normalised weight of i-th criterion; where: X_i is the standardised score (Malczewski, 2000).

The obtained maps (Fig. 5) represent a spatial decision-support tool able to identify suitable areas for the location of healthcare facilities, as they point out the most suitable area under a multidimensional evaluation perspective. According to the Functional Quality, sites located close to the city center show a lower suitability level compared to suburban ones. The Location Quality confirms the previous trend and it

Table 2
Criteria for the location of Healthcare facilities.

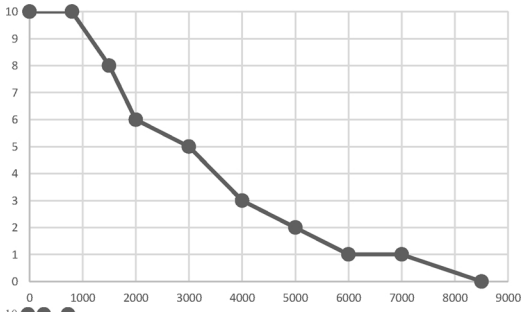
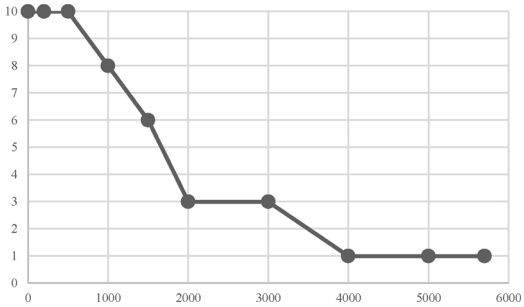
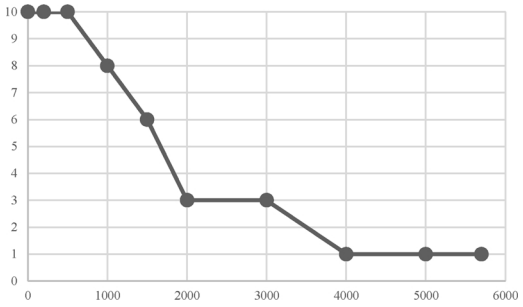
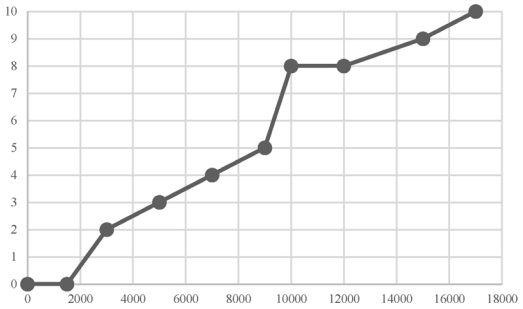
Goal	Main objectives	Indicators	Description	Scale	Source Data
Prerequisites		Existing hospitals	The criterion represents existing hospitals in the Municipality of Milan	1:10000	Map of existing healthcare facilities (Geoportale comune Milano)
		Areas of hydrological and hydraulic instability	The criterion represents the presence of rivers and canals		Map of Milan's rivers (Geoportale Regione Lombardia)
Hospital site selection	Functional Quality	Centre of Urban redevelopment	The criterion represents abandoned areas with information regarding area, land use, year of disposal, possible use after disposal, degree of preservation	1:10000	Abandoned areas map of the Lombardy Region (Geoportale Regione Lombardia)
		Flexibility	The criterion represents the different types of land cover	1:50000	land use map of the Municipality of Milan (Geoportale comune Milano)
		Building density	The criterion aggregates information related to the population distribution and percentage of people older than 65 years	–	Istat: resident population and age of the population (2014)
	Location Quality	Accessibility	The criterion aggregates information related to the private and public mobility and the availability of parking lots	1:5000	Highway, primary road, subway stop, bus stop and public parks map (Geoportale comune Milano)
		Services	The criterion aggregates main important services in the Municipality of Milan	1:10000	Shopping mall, shops, school, churches, healthcare facilities map (Geoportale Regione Lombardia)
		Green area	The criterion represents the presence of parks, garden and green spaces	1:1000	Green areas map (geoportale Regione Lombardia)
		Network infrastructures	The criterion has been represented considering the sewerage system	–	PUGGS of the Municipality of Milan
	Environmental Quality	Noise pollution	The criterion represents the acoustic classifications approval status	1:10000	Acoustic plans map (Geoportale comune Milano)
		Air pollution	The criterion aggregates information related to the level of pollution of three different pollutants: PM10, O3, NO2	–	ARPA Lombardia: PM10, O3, NO2 annual average (January 2016-December 2106)
		Unhealthy industries	The criterion represents the presence of industrial activities	1:1000	Location of Technological Network buildings map (Geoportale comune Milano)
	Economic Aspects	Value of the area	The criterion represents the monetary value of the area per sqm.	–	Value of building areas in the Municipality of Milan considering possible negotiation (Comune di Milano)
		Land ownership	The criterion represents the types of properties of the area and its size and level of segmentation	–	Properties of the area (Catasto)
		Land suitability	The criterion represents the level of suitability of the areas, its current situation	–	Map of contaminated and reclamated areas (Geoportale comune Milano)

Table 3
Description of the standardization functions.

Indicators		Standardization	Value function
Centre of Urban redevelopment		Distances ≤ 500 m are standardized to 10. Distances between 500 and the max Distances are standardized according to the linear score (the lower the Distances, the higher the score). Ranges have been defined every 1000 m.	
Flexibility		Scores have been defined according to the population resident in each district of the Municipality of Milan and the percentage of people > 65 years.	–
Building density		Scores have been defined according to land use, areas more suitable as the abandoned one are standardized to 10 while the unsuitable one as protected sites are standardized to 0.	
Accessibility	Public	Bus: Distances ≤ 400 m are standardized to 10. Distances between 400 m and 1500 m are standardized according to the linear score (the lower the Distances, the higher the score). Distances > 1500 m are standardized to 3 (15 min walking Distances).	
		Metro: Distances ≤ 800 m are standardized to 10. Distances between 800 and 2000 are standardized according to the linear score (the lower the Distances, the higher the score). Distances between 2000 m and 3000 m are standardized to 3 (30 min walking Distances). Distances between 3000 m and the max Distances are standardized to 1.	
	Private	Distances ≤ 500 m are standardized to 10. Distances between 500 m and 3000 m (15 min car Distances) are standardized according to the linear score (the lower the Distances, the higher the score) until the score 6. Distances between 3000 m and the 5500 m are standardized from 3 to 1. Distances ≥ 5500 m are standardized to 0.	
	Parking	Distances ≤ 800 m are standardized to 10. Distances between 800 m and 2000 m are standardized according to the linear score (the lower the Distances, the higher the score). Distances between 2000 and 3000 (30 min walking Distances) are standardized to 3. Distances between 3000 and 7000 are standardized to 1. Distances ≥ 7000 m are standardized to 0.	
Services		Distances ≤ 800 m are standardized to 10. Distances between 800 m and 7000 m are standardized according to the linear score (the lower	

(*continued on next page*)

Table 3 (*continued*)

Indicators	Standardization	Value function
	the Distances, the higher the score). Distances ≥ 7000 m are standardized to 0.	
Green area	Distances ≤ 500 m are standardized to 10. Distances between 500 m and 1500 m (15 min walking Distances) are standardized according to the linear score (the lower the Distances, the higher the score). Distances between 1500 m and 3000 m are standardized to 3. Distances between 3000 m and the max Distances are standardized to 1.	
Network infrastructures	Distances ≤ 800 m are standardized to 10. Distances between 800 m and 5000 m are standardized according to the linear score (the lower the Distances, the higher the score). Distances between 5000 m and 7000 m are standardized to 1. Distances ≥ 7000 m are standardized to 0.	
Noise pollution	Scores have been defined according to the acoustic classification defined for the Municipality of Milan and the max emission regulated by the law. 0 dB is standardized to 10; 50 dB are standardized to 10; 55 dB are standardized to 7; 60 dB are standardized to 5; 65 dB are standardized to 3; 70 dB are standardized to 1.	–
Air pollution	Scores have been defined according to the level of pollutants present in each district of the Municipality of Milan according to the position of detected stations.	–
Unhealthy industries	Distances ≤ 1500 m are standardized to 0. Distances between 1500 m and 15000 m are standardized according to the linear score (the higher the Distances, the lower the score). Distances ≥ 15000 m are standardized to 10.	

is evident how suitable sites are the most accessible ones. Finally, the third map shows a distribution of suitability levels divided in three main zones with increasing values moving from the northern part of the city to the southern one.

4. Results and discussion

4.1. Results of the first application

The Overall Suitability Maps (Fig. 6) is obtained by the linear aggregation of the three macro areas according to the WLC, as explained previously. Since the most important one according to experts' preferences is the Location Quality, the most suitable areas to locate hospitals are the suburban ones. What it is important to underline from this first attempt is that the maximum final value obtained is 8, while no sites got 10 as overall score, meaning that, even if there are areas more suitable than others, no one is the optimal according to the structure of the decision problem under investigation.

Moreover, it is possible to overlap the pre-requirements previously defined in the Multi-methodological framework as constraints. In fact,

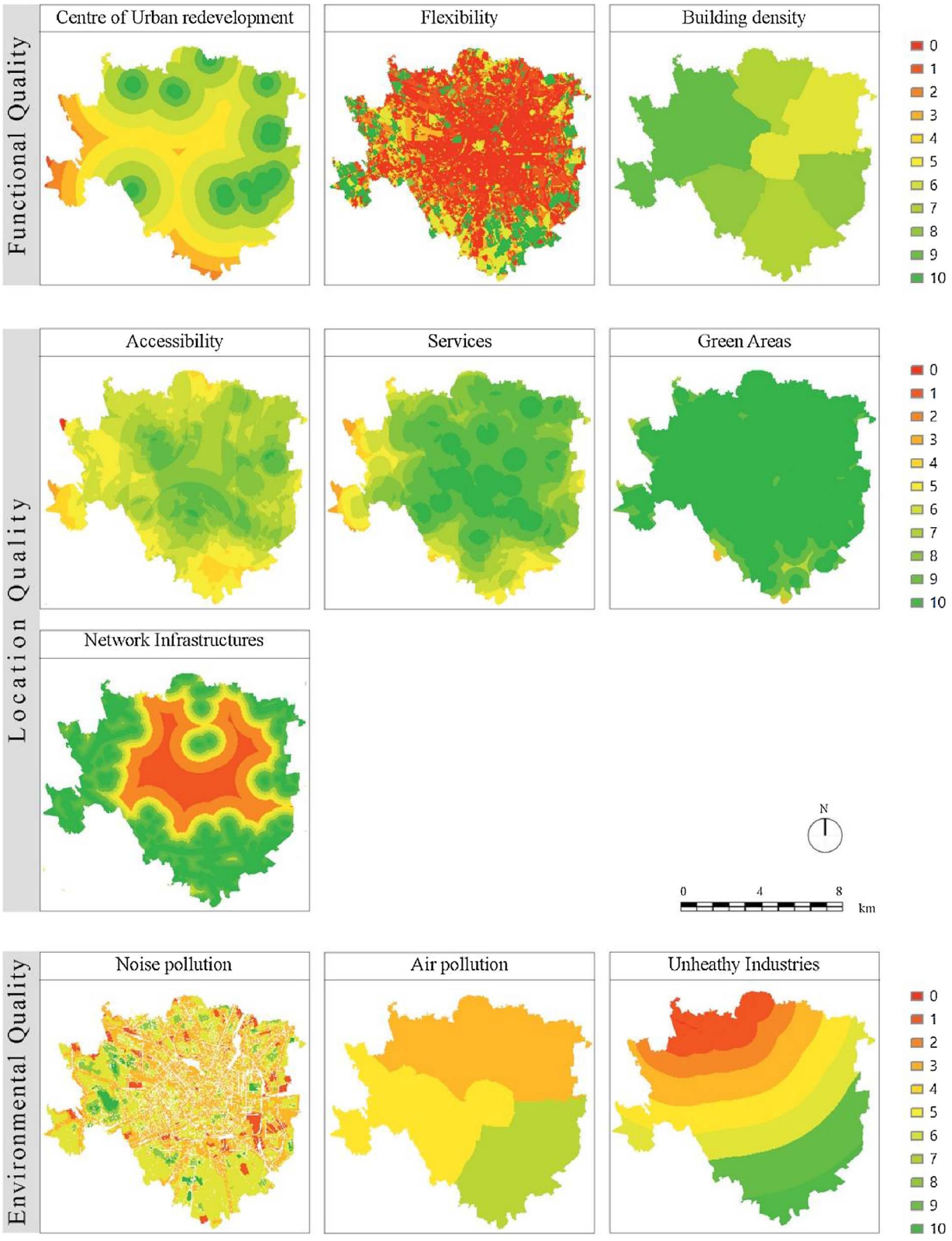


Fig. 4. Sub-criteria after standardization (N.B. colour should be used).

these two layers can be evaluated as restrictions to be removed from the analysis and to not be considered as potential sites for the hospitals' location. In particular, since the purpose is to locate an hospital in the Municipality of Milan, the existing hospitals have been underlined with a blue colour in order to understand their location on the territory and to provide a future equal distribution by choosing an area considering the distance from them. The second layer deals with areas under hydrological and hydraulic instability in order to highlight river banks and areas subjected to phenomena such as landslides, floods, etc. These areas could affect negatively the construction process.

The last map of Fig. 6 overlaps the potential candidate sites identified from the local administration for the location of "La Città della

Table 4
Criteria weights elicitation.

Criteria	Weights (C)	Sub-criteria	Weights (I)
Functional Quality	23%	Centre of Urban redevelopment	9%
		Flexibility	64%
		Building density	27%
Location Quality	34%	Accessibility	44%
		Services	9%
		Green area	4%
		Network infrastructures	43%
Environmental Quality	25%	Noise pollution	24%
		Air pollution	63%
		Unhealthy industries	13%
Economic Aspect	18%	Value of the area	14%
		Land ownership	43%
		Land suitability	43%

Salute". For the purpose of this paper only sites located in the Municipality of Milan have been considered. It is possible to see how most of them belongs to areas threated by hydrological and hydraulic instability or are close to them as Area 2, Area 3 and Area 5, while others have obtained a low score (between 3 and 4) as Area 1 and Area 4. This result better underlines how the process of selection of a site for the location of a fundamental and essential service for the community, as the healthcare one, should be guided by a robust evaluation methodology in order to prevent possible negative effects and irreparable mistakes (Fehr and Capolongo, 2016).

Furthermore, these maps help to pointing out how sites previously identified for the location of "La Città della Salute" are less suitable than others according to the set of criteria considered. This issue brings to light how also that the generation of alternatives itself can be considered as a decision problem (Colorni and Tsoukiàs, 2017). The definition a priori of few options can simplify the process of selection but at the same time exclude other sites and important details useful for the DM in order the make a conscious choice.

4.2. Discussion of the results

The present work provides a multi-methodological evaluation approach for supporting complex decision problems as the hospitals' siting. The proposed methodology has been applied to the location of a new hospital in the city of Milan (North of Italy) as pilot case study with the purpose of testing its usefulness and robustness, but it can be also tested on other contexts.

One critical aspect concerns the Economic Dimension that have not been considered in the MC-SDSS, but that should be been taken into consideration in a second phase of the decision process accoding to the agreements between parties. In fact, once identified a finite number of suitable alternatives, the site selection should pass through the analysis of Land value, Land Ownership and Infrastructural quality with the support of the MCDA.

Another step to better define is the role of DMs in the decision process by the definition of an interactive protocol. They have been involved only for the criteria weights elicitation phase, but it could be interesting to frame the standardization procedures according to their opinions. A possible way to overcome this problem is to perform the sensitivity analysis that can allow to test the robustness of the results obtained by stressing the weights and assigning a percentage of uncertainty to the scores with respect to the potential lack of information.

5. Policy implication

Considering the results of the proposed application, it is evident how increasing the transparency of the decisions, by putting in evidence weakness and strengths imposed by the choices of the area, is consistent to the notion of constructive evaluation that expresses all its potentials when it is meant as a supporting activity of the decision making process (Oppio et al., 2016). What's new with respect to the traditional decision making process is that the partial and final maps allow to generate new alternatives in addition to the ones given.

This kind of evaluation framework could support the public health policies at two different stages.

The first concerns the location of new healthcare facilities when a finite number of alternatives has not been defined yet, as it has been presented in the paper, or to identify the most suitable one among a specific set. In this way DMs could be guided in the whole process and could interact with the analyst – in charge to support them – during the standardization procedures and the criteria weights elicitation, since the strength of the methodology proposed is its flexibility to be changed and adapted to different contexts. In fact, DMs could assign a different degree of influence to the set of criteria and define different thresholds of acceptability and ranges during the standardization procedure.

The second stage could be the use of the proposed methodology within an *ex-post* evaluation activity. It means that, whether the location of the new hospital has already been chosen, the tool could be used to check the real suitability of the area and, in case of critical aspects, it could effectively address design strategies to solve or limit weaknesses

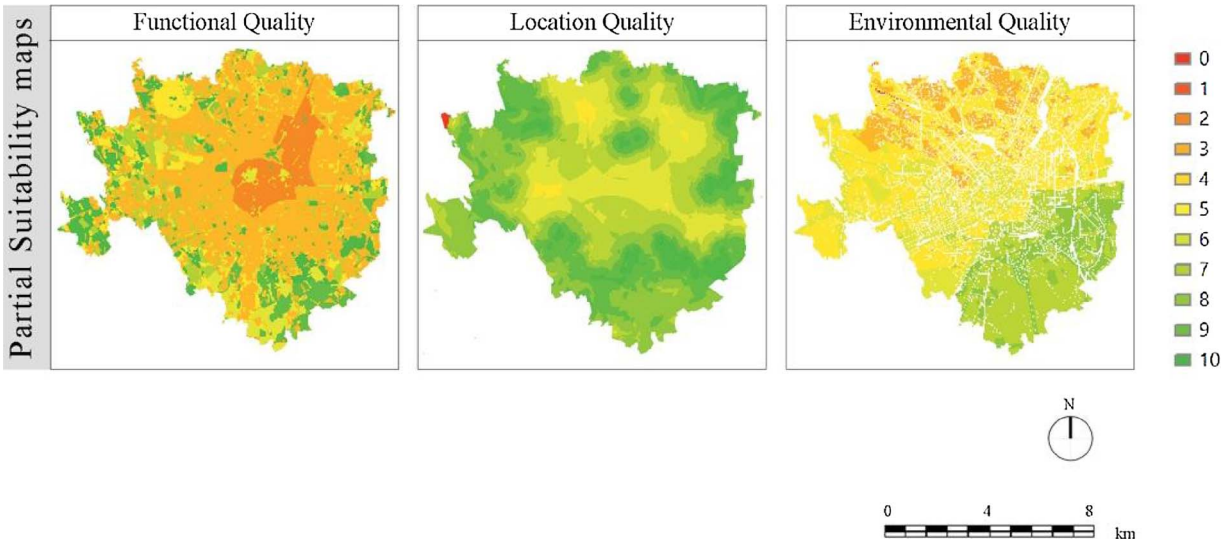


Fig. 5. Suitability maps for each criterion. (N.B. colour should be used).

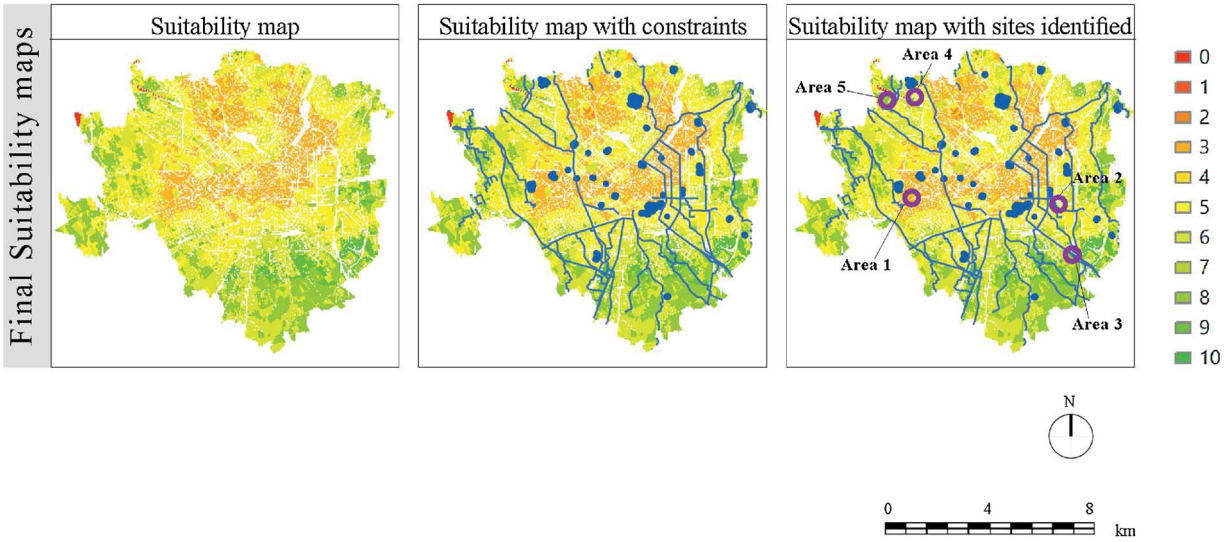


Fig. 6. Final Suitability maps with and without prerequisites and with potential candidate sites for the location of "La Città della Salute". (N.B. colour should be used).

and threats. In fact, both the Partial and the Overall Suitability maps provide information about advantages and disadvantages of each area.

This tool if better investigated and if the standardization procedure better defined could became a strong support for authorities to make location choice and to communicate results to the community in a transparent way.

In conclusion, what emerges from this first application is the importance to approach site decisions about hospitals by considering environmental, location and functional factors, in addition to the economic ones, as well as to involve in the process different categories of stakeholders trying to satisfy their expectation and needs. Furthermore, the combination of MCDA and GIS could address decisions by considering simultaneously multiple dimensions of the problem under investigation and the maps could facilitate to interpret and communicate the results, by aggregating several layers of information and data.

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